EXHIBIT "F"

Physical Review Letters Magnetic Monopole Article

Overview of "*Evidence for Detection of a Moving Magnetic Monopole*"

The balloon-borne experiment that resulted in the above-entitled article was launched in 1973 and returned shortly thereafter. The detectors were separated into two batches, with the emulsion and Cerenkov detector portion sent to Texas for analysis, and the Lexan stack detector sent to Berkeley. When the Lexan stack detector [which was the great bulk of the detector array] arrived in Berkeley circa October, 1973, it was stored away for future analysis, as analysis of the SkyLab detector was then underway, which lasted until circa May, 1975.

I was the party primarily responsible for the analysis of the SkyLab detector, though various assistants worked with me from time to time, and Dr. Ed Shirk developed much of the equipment used in the analysis. Circa May, 1975 I announced that I planned to depart Berkeley at the end of July, 1975 to attend law school. I was immediately tasked with doing the analysis of the balloon-borne detector that had been stored away 1½ years earlier, in light of the fact that I was the one person who could do so in the allotted time.

Accordingly, I developed an analysis plan that would last 10 weeks, which I shared with Dr. Shirk, and then commenced with the analysis. This analysis required a preliminary triple-scan [to insure all interesting events were noted] of the detector's surface area with scanning stereo-microscopes, followed by measurement of the interesting events with 1600X oil-immersion microscopes. Due to time constraints, I was not able to complete the preliminary oil-immersion measurements of the approximately 40 interesting events [those with an estimated high-Z based on their stereoscopic scans and preliminary 3-sheet measurements] until approximately one week prior to my scheduled departure on July 31, 1975. These measurements were then run through Dr. Shirk's program for display on graphs, and calculating of charge estimates. Dr. Shirk then provided to me the data I had been gathering, in a sheaf of print-outs, which displayed two pages for each interesting event.

As I leafed through the sheaf of print-outs of my data, I noticed one event in particular that was completely anomalous from the some 10,000+ high-energy cosmic ray tracks I had been observing over the preceding 1½ years. Its characteristics were anomalous for a number of key reasons:

- Its estimated charge was exceptionally high, at 137. Previously, the highest estimated charges had been at about 92 [Uranium], with no trans-Uranics detected.
- Its ionization rate was exceptionally uniform, showing no slowing through the stack. All previous cosmic ray tracks had always showed slowing, no matter the charge or energy, with the most energetic tracks ever seen showing a doubling of ionization from one side of the stack to the other [on the Skylab, cosmic rays came from both directions; on the balloon, they only came from the top].
- Its error-bars on the charge estimate were reported as zero. Since the program rounded to whole numbers, that could have allowed for a small error bar of less than +/- ½ charge. All previous cosmic ray measurements had always had some error in charge estimate, resulting in error bars typically at +/- 2-3 charges. A few had error bars of only 1 charge. Never before in any of my measurements had there been error bars with the value at zero charge.
- Its angle of incidence, which had been fortuitous at roughly 23 degrees and ideal for measurement under the microscope, also did not vary through the stack, with error-bars likewise at zero [with reporting rounded to the nearest 1/10th degree]. There was no evidence of collision [by slight change in angle of incidence] with detector nuclei, as would be occasionally seen for some cosmic rays.

Based on that preliminary information, I was initially inclined to believe that we had detected an ultra-relativistic, very high-energy cosmic ray of charge of approximately 137. However, as I sat and pondered the evidence, I recognized that such a nuclear charge should not exist, as it would be in the 'valley' of the "islands of nuclear stability" that are posited to exist beyond Z = 96, and hence highly unstable and therefore unable to exist naturally.

I then recalled P.A.M. Dirac's prediction that a theoretical magnetic monopole would behave in matter such that it would cause an ionization equivalent to an electric charge of 137, even if slowing. I was aware that Dirac had successfully predicted the existence of the positive electron [positron], and thus I believed we instead had evidence that showed his magnetic monopole prediction to also be correct.

Consequently, I then approached Dr. Shirk, who was sitting a few feet away from me at the time, showed him the data, and asked him:

> "Do you think it's a monopole?"

Dr. Shirk agreed with my conclusion, and both of us then walked down the hall to Dr. Price's office, showed him the data, and asked him if he believed it was evidence for a magnetic monopole. He too agreed.

Over the next few days, the intervening sheet data [black dots on Figure 2, whereas the triangles represented the data I had before me initially with which I initially identified the candidate event as a magnetic monopole] was also developed and analyzed, and fit very well with the existing data, and resulted in no change in charge estimate.

Also, a call was placed to Texas to develop the Cerenkov detector, which had not yet been analyzed. That came back that the velocity of the particle was less than the speed of light in clear Lexan [about 0.68c]. Any normal nucleus with a speed that slow would have exhibited strong slowing in the stack, again ruling out a high-Z particle at ultra-relativistic speed.

The suggestion was made that a doubly-fractionating normal nucleus would somewhat mimic the data. However, it would require wide error-bars on such a doubly-fractionating normal nucleus to exactly mimic the data. The question then arises, where were all of the doubly-fractionating normal nuclei that came close to, but did not quite mimic the monopole data? None were seen in the 10,000+ cosmic ray tracks I had already observed that even came close. The odds against that were more than 1 Billion to 1, but since flukes can happen, I have concluded that additional evidence is warranted, such as could be provided by the AMS-2 [which can detect not only strangelets, but magnetic monopoles as well].

After finalizing the measurements of the intervening sheets, I only had one day prior to my scheduled departure on July 31, 1975. I then departed for Hana, Maui, where I lived for approximately 3 weeks before moving back to California to begin law school studies circa September 1, 1975. During that period of time on Maui, I had requested that Dr. Price prepare my data, notes, etc. for publication of an article in a journal of his choosing. He did so, but decided to remove my name as the party responsible for the discovery, for unknown reasons. While he and Dr. Shirk, as well as the Texas investigators, are properly co-authors, it was not proper to place my name solely as a "contributor".

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Evidence for Detection of a Moving Magnetic Monopole

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A very heavy particle passed through a balloon-borne stack of Cherenkov film, emulsion, and Lexan sheets. In 33 Lexan sheets it produced tracks expected of either a nucleus with $125 \lesssim Z \lesssim 137$ and $\beta \lesssim 0.92$ or a magnetic monopole with $g = 137e$. Its track structure in emulsion indicated it was moving downward with $\beta = 0.5^{+0.1}_{-0.05}$ and was either a nucleus with $Z \approx 80$ or a monopole with $g = 137e$. These facts strongly favor identification of the particle as a magnetic monopole of strength $g = 137e$ and mass $> 200 m_p$.

In the last of our series of balloon flights to study ultraheavy cosmic rays ($Z \gtrsim 60$) at low geomagnetic cutoff, the multilayer stack, 20 m^2 in area, shown in Fig. 1, was exposed for 2.6 days at an atmospheric depth of ~3 g/cm^2 near Sioux City, Iowa, on 18 September 1973. Here we present our analysis of one event that differs from any seen in previous balloon flights[1] or in the Skylab ultraheavy-cosmic-ray experiment.[2]

The event was found in a stereomicroscopic scan of the emulsion layer and was recorded as having $Z \approx 80$ and $\beta = 0.5^{+0.1}_{-0.05}$ on the basis of track-structure measurement made with an eyepiece reticle and a microscope. The estimates of Z and β guide us in choosing the optimum times for chemically etching the portions of the Lexan sheets along a particular event. Cone-length measurements in the Lexan then yield much more precise estimates of charge and velocity. The fast-film Cherenkov detectors furnish independent velocity estimates for $Z \gtrsim 70$ and $\beta > 0.68$. Figure 1 summarizes the information derived from each type of detector. Only the interpretation of the particle as a magnetic monopole with $g = 137e$ and $\beta \approx 0.5$ is consistent with all the available information.

Figure 2 shows the data from the Lexan detector. The triangles represent data from a 20-h etch and the solid circles for a 30-h etch in a separate tank.[3] All measurements were made by two observers. The points reproduce to within ± 0.05 μm/h.

In previous analyses[2,3] of ultraheavy cosmic rays we have found the etch rate v_T depends on ionization rate approximately as

$$v_T = \mathrm{const}(Z^*/\beta)^4, \qquad (1)$$

where Z^* is the effective charge. The scale at the bottom of Fig. 2 is the estimated charge assignment if $\beta \approx 1$. The best fit to the data is given by a zero slope (rate of change of etch rate with depth), corresponding to a hypothetical charged particle with $Z \approx 137$ and $\beta \approx 1$. For the maximum slope, S_{max}, consistent with the data (84% confidence), the charge is $Z \approx 125$ and $\beta \approx 0.92$. In no previous flight with Lexan detectors has an event been found with $Z \gtrsim 96$. This is reasonable because $^{247}_{96}Cm$ is the heaviest known nuclide with a half-life (in its rest frame) greater than 10^6 yr.

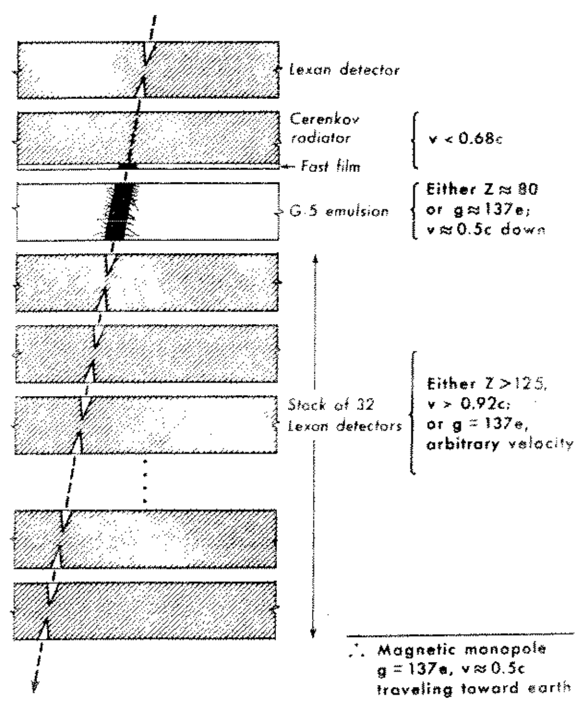

FIG. 1. Stack of balloon-borne detectors.

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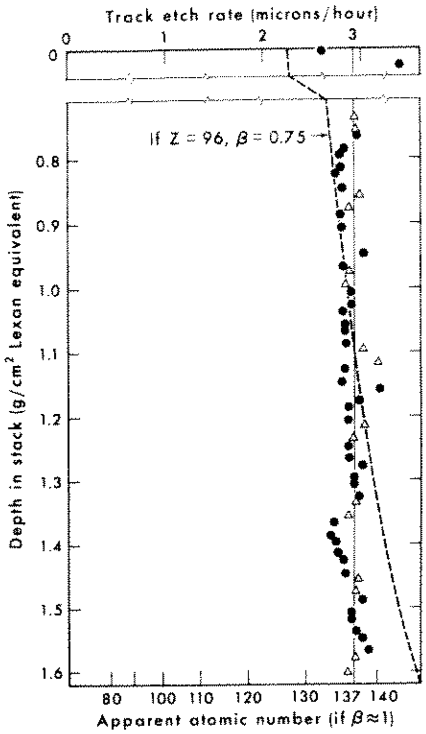

FIG. 2. Etch-rate data. See text. Emulsion data rule out dashed curve or any fit to a nucleus with $\beta > 0.5^{+0.1}_{-0.05}$.

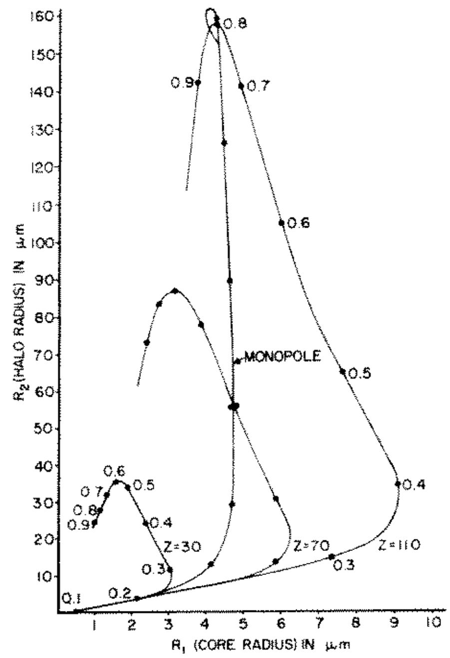

FIG. 3. Method of estimating charge and velocity from track structure in emulsion. See text. Numbers along curves give $\beta = v/c$.

The dashed curve in Fig. 2 shows the best fit to the data for a nucleus of $Z = 96$; its velocity must be $\sim 0.75c$; its slope is ~ 18 times S_{max}. The ionization rate of a magnetic monopole of strength g is given[5-7] by replacing Z^*e by $g\beta$, so that for a monopole Eq. (1) must be replaced by

$$v_T = \text{const}(g/e)^4. \qquad (2)$$

The solid line in Fig. 2 is consistent with a monopole of strength twice the minimum strength $g_0 = \hbar c/2e = (137/2)e$ of Dirac's hypothetical magnetic monopole.[4] Thus, the etch-rate data admit of only two alternatives:

(1) The particle was a nucleus with $Z \gtrsim 125$, $\beta \gtrsim 0.92$.

(2) The particle was a monopole with $g = 137e$ and any velocity sufficient to penetrate the 1.6-g/cm^2 stack.

The data from the nuclear emulsion and Cherenkov film enable us to reject the first alternative. One of us[8] has extended the track model of Kobetich and Katz[9] and their electron-energy-deposition algorithm[10] to obtain detailed predictions of ion-track structure from the track core out to the maximum lateral extent of the δ rays for wide ranges of Z and β. Subsequently, we[11] modified these calculations to include the Mott cross section[12] rather than the Rutherford cross section. These results are in agreement with our accumulated experience from almost 100 ultraheavy-cosmic-ray events, and allow us to predict monopole-track structure by the substitution $Z^* = 137\beta$. Katz and Butts[7] predicted monopole-track core widths based on the Rutherford cross section, but did not consider structure outside of the core region. A useful way to display our results is to plot R_1, the radius at which the probability of grain development is 0.4 versus R_2, the radius at which the probability of grain development is 0.001. R_1 corresponds to the core radius and R_2 to the limit of visual perception of a signal above background. Figure 3 contains results for $Z = 30$, 70, and 110, and for a monopole with $g = 137e$.

Because of the steepness of the track, R_1 could not be measured accurately but was ~ 6 μm. The observed R_2 was 55 μm, consistent with a monopole with $\beta \approx 0.5$, but totally inconsistent with the R_2 (130 μm) expected for a nucleus with $Z > 125$ and $\beta > 0.92$. Observations of Fe tracks that stopped in the Lexan showed that the emulsion had normal sensitivity.

Our measurements show that, among the identifiable individual δ rays, downward-directed tracks outnumber upward-directed tracks by at

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FIG. 4. Photomicrographs of the monopole track in (a) a Lexan sheet (epoxied, sliced, and viewed edge-on), and (b) G-5 emulsion (viewed nearly vertically). In (c), note the greater lateral extent of δ rays from a nucleus with $Z \approx 92$ and $\beta \approx 0.6$.

least 5 to 1. We conclude that the monopole was moving downward.

Figure 4 shows photomicrographs of the monopole track in one sheet of Lexan and in the emulsion, together with a photomicrograph of the track of the heaviest nucleus found in the flight. From its R_1 ($\sim 5\ \mu$m) and R_2 (110 μm) in emulsion it was estimated to have $Z \approx 95$, $\beta \approx 0.65$. It came to rest in the Lexan stack. Measurements of its etch pits showed that $Z \approx 92$ and $\beta \approx 0.6$ at the emulsion.

A fast-film Cherenkov detector consisting of a thin plastic Cherenkov radiator, coated with Eastman Kodak 2485 film, records an elliptical image at the trajectory of a charged particle of $Z \gtrsim 70$ and $\beta > \beta_{\rm crit} \equiv n^{-1}$, where n is the refractive index of the radiator.[3,13] The intensity of the image is proportional to $(Ze)^2(1 - n^{-2}\beta^{-2})$ for a charged particle and to $g^2(n^2 - \beta^{-2})$ for a monopole. We have examined the appropriate region of our fast-film Cherenkov detector and have found a small ionization spot but no elliptical Cherenkov image. Eight other regions traversed by high-energy, high-Z nuclei during this flight showed normal Cherenkov images. We conclude that the particle in question had a velocity $\beta \lesssim 0.68$ in the Cherenkov radiator.

Independent of all details of calibration of response of the Lexan and the emulsion, the essence of our observations is that we have found a particle of velocity $\sim 0.5c$ that ionized heavily and at a constant rate as it slowed down through 1.6 g/cm^2 of matter. This constancy of ionization rate was first shown by Dirac[4] to be a property of magnetic monopoles. A particle with only electric charge and velocity $0.5c$ would have to have an enormous ratio of mass to charge to fit the data ($>10^4$ proton masses and $Z \approx 70$). Neither a Lee-Wick abnormal nucleus[14] nor a small, charged black hole[15] is consistent with the evidence.

We conclude that we have detected a magnetic monopole of strength $g = 137e$ and velocity $(0.5^{+0.1}_{-0.05})c$. In order to penetrate the ~ 1-g/cm^2 Lexan stack its energy must exceed 32 GeV, which means that its mass must exceed ~ 200 proton masses. Its existence rules out the existence of free quarks or other fractionally charged particles.

Based on this one event out of numerous balloon flights and one satellite exposure of large detectors of heavily ionizing particles, the flux of monopoles of strength $137e$ near the top of the atmosphere with velocity sufficient to penetrate track detectors is $\sim 10^{-13}$ cm^{-2} sec sr. The apparent conflict between this flux and the negative results obtained in previous monopole searches[16] places strong constraints on the properties of monopoles.

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